TWO-WAY COMMUNICATION THROUGH AN ORAL-BASED TACTILE INTERFACE: PRELIMINARY RESULTS

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Abstract – **A two-way tactile communication system incorporating oral-based tactile modes is developed. The prototype system allows the user to both receive navigation cues, via a microfabricated flexible electrotactile palate display, and transmit information to the outside environment using a tongue operated device (TOD). The palate display consists of a flexible electrocutaneous-mode 7x7 electrode array for stimulating the palate. The TOD has four switches laid out in the cardinal directions with a fifth switch in the center. An oral-based tactile interface is realized by integrating the palate display and the TOD using a dental palate mold made from a silicone impression material. The system is programmed to test and simulate navigational guidance via two-way tactile communication. Preliminary human subject tests have been performed. Results indicate TOD force requirements influence performance, but adequate performance can be achieved within a relatively large range of input forces (one order of magnitude).**
Keywords – **electrocutaneous, oral, palate, switch, tactile, tongue.**

I. INTRODUCTION

Research on tactile devices as a mode of communication has recently increased in the past several years. Much of the work has been focused on implementing devices to aid the visually impaired in understanding graphical user interfaces (GUIs) commonly found on computers. Prior work has been directed towards converting text into sound, enabling the individuals to access and understand written text. However, such a system is futile to people with auditory impairments, or those possessing both visual and auditory impairments. The development of tactile displays capable of displaying textual and graphical information would allow access to advanced computers, reading, and navigation [1, 2, 3]. In addition, the transmission of information via the tactile sensory would establish a hands-free system with minimal disturbance to the surrounding environment and could reduce sensory overload [4].

Recently, tactile displays have been designed to send information to a person via the tactile sense through various modes of stimulations – electrostatic, electrocutaneous (EC), and vibrotactile. Systems such as the Optacon™ are designed for the fingertip, while other tactile displays target relatively larger and flatter parts of the body, e.g., the abdomen and the back [5, 6]. However, there are several limitations with such displays as they are relatively bulky and, power hungry, while the density of the cutaneous sensors on these regions of the body is comparatively low.

The tissues of the oral cavity are some of the most sensitive in the body, and preliminary studies of its potential as a stimulation site are encouraging [4, 7, 8]. Oral structures possess a cortical mapping similar in size to that of the hands, while the entire trunk and lower half of the human body have fairly small mapping in the somatic sensory cortex [9]. Taking advantage of this superior sensitivity, applications for an oral-tactile interface to assist individuals with vestibular dysfunction, quadriplegia, and navigational guidance, e.g., scuba divers, look promising. With the aid of advancements in microfabrication, a tactile device may be placed within the oral cavity, providing a novel approach for sensory augmentation, communication, and human-computer interface. However, the oral cavity does present challenges – it is not readily accessible and possesses few large flat areas for stimulation [4].

Several companies have recognized the potential merits of tongue-based devices, such as NewAbilities Systems' tongue touch keypad (TTK) (Mountain View, CA), and IBM's Tonguepoint prototype [10]. Though, innovative, they are only capable of communicating in one direction, i.e., sending information from the user to the outside world. Our preliminary work on a two-way communication tool was encouraging [4], and highlighted several areas where improvement was necessary. In this paper, we demonstrate an oral-based tactile interface that affords two-way communication and addresses some of

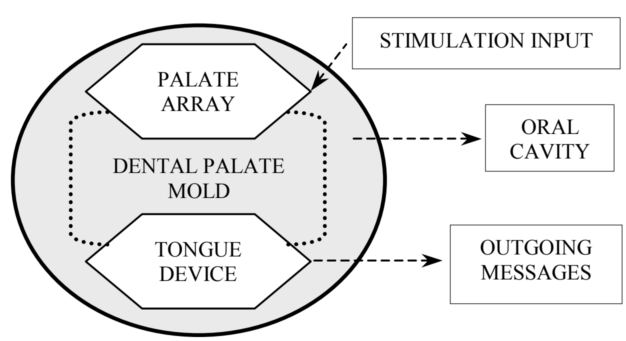

Fig. 1. Oral tactile interface with both input and output capabilities.

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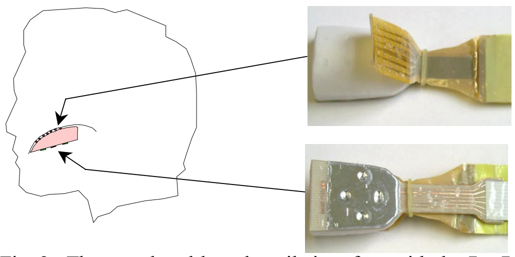

Fig. 2. The actual oral-based tactile interface with the 7 × 7 palate array on top, and the TOD on the bottom of the dental palate mold.

the deficiencies of the previous device. The focus of our preliminary tests are on the TOD to investigate its integration with the palate display, and to assess its functionality and design. The oral interface concept and a prototype device are illustrated in Fig, 1 and Fig. 2, respectively.

II. INTERFACE IMPLEMENTATION

Our ultimate goal is to develop a self-contained device that affords a discrete hands, vision, and audition-free communication system for two-way communication via wireless technology. To that end, we have developed a prototype oral-based tactile interface consisting of a dental palate mold that includes the flexible electrode array for palate stimulation, and a five-switch tongue operated device (TOD). Fig. 1 presents the oral tactile interface between the user and the outside world. The user receives information via the EC palate array by sensing and recognizing dynamic tactile patterns (e.g., lines, shapes, arrows, etc.). The user can also simultaneously send a message by depressing one of the switches on the TOD.

The tongue is well suited to operate the TOD because of its mobility and tactile sensitivity. Similarly, the palate is used for the EC stimulation since it is relatively flat and large, sensitive to low-intensity tactile stimulation, and the array can be in constant contact with it. Such a design would allow simultaneous operation of both input/output devices. Fig. 2 shows the current version of the interface and its placement within the oral cavity.

A. *Palate Display*

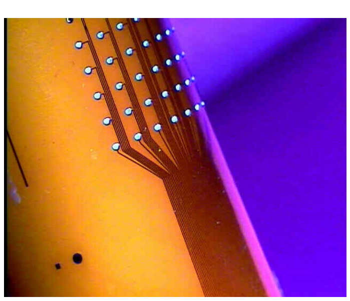

Fig. 3. A polyimide-based flexible palate array wrapped around a cylinder of approximately 26 mm in diameter.

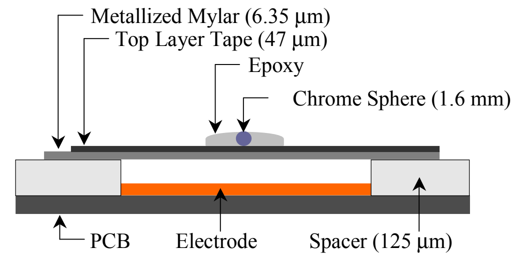

Fig. 4. Cross-section of one of the switches of the TOD.

Using microelectronics fabrication techniques and processes, the flexible palate array fabricated is a multi-layered polyimide-based display consisting of a 7 × 7 matrix of dome-shaped electrodes, each approximately 200 µm high and 700 µm in diameter. The array, as shown in Fig. 3, is fabricated with thin-film technology and a subsequent nickel electroplating process [11]. The bright dots are the dome-shaped electrodes with the traces serving as interconnections between the array and the control circuitry. Overall dimensions of the array are 18.5 × 18.5 mm^2, with a center-to-center electrode spacing of 2.54 mm. Thin-film technology processing allows the development of a flexible display that will conform to the roof of the mouth. In addition, the dome-shaped electrodes theoretically provide a more uniform current distribution that also increases its surface area for EC stimulation, improving the dynamic range of current stimulation, and the quality of the tactile perception by the user by decreasing the localized current density [4].

B. *Tongue-operated Device (TOD)*

We have fabricated tongue switches that are directly hardwired using printed circuit board (PCB) kits from Kepro Circuit Systems, Inc. (St. Louis, MO). The five switches were laid out using AutoCAD in a cardinal direction, with the fifth switch in the center. The pattern was transferred to the PCB by photoresist development, and a subsequent copper etching process. TODs were fabricated and machined to include a small paddle to allow the user to manipulate the interface to the best position in the oral cavity. Several configurations of the spacing layer thickness (3M double-sided adhesive, St. Paul, MN), metallized Mylar thickness (Dupont), and size of spheres (switch location 'nibs') were tested in preliminary human subject experiments (see Fig. 4). Depressing the 'nib' that lies on top of the metallized Mylar film shorts the interdigitated leads on the 'PCB electrode', thereby closing and completing the direction-specific circuit. The ability of the user to depress the tongue switches was observed to determine the optimal configuration (both geometric and force required).

C. *Integration of the Palate Display and TOD*

The oral-based tactile interface is realized by integrating the palate display and the TOD using a dental palate mold, as shown in Fig. 2. The dental palate mold is

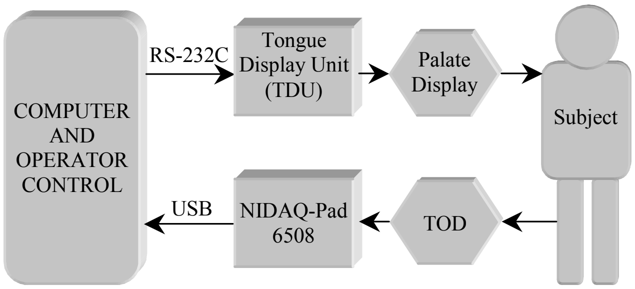

Fig. 5. System configuration for a two-way communication interface.

made from a silicone impression material (CutterSil Putty Plus, Heraeus Kulzer, Inc., South Bend, IN). Various combinations of the mold and hardener were attempted until a pliable, yet supportive mold was fabricated. The palate array is mounted on top of the palate mold to ensure contact with the anterior portion of the roof of the mouth, while the TOD is mounted on the bottom-side of the dental palate mold using 3M Super Glue gel (St. Paul, MN). This configuration allows simultaneous use of the palate display and the TOD. Both the palate display and the TOD are connected to the outside circuitry via flexible cables [4].

III. Simulation Configuration

To demonstrate and characterize the performance of the two-way tactile communication system, a computer-controlled system was implemented to interact with both the palate display and the TOD. The computer system controls the presentation of tactile patterns and interprets the signals from the TOD in real time. The simulation environment from previous research [4] is modified such that it can control the palate display and receive input from the TOD, as opposed to the TTK.

A. *Hardware Configuration*

The oral components (palate display and TOD) are integrated with the associated hardware to create a computer-controlled system as shown in Fig. 5. The palate display is connected to the Tongue Display Unit (TDU – ver. 1.1, Wicab, Inc, Madison, WI) through two 40-pin IDC cables. The TDU is a programmable tactile pattern generator with tunable stimulation parameters for each electrode via a standard RS-232C serial link to a PC. The TOD is connected to National Instruments DAQPad-6508 (Austin, TX), an external data acquisition device, via a USB communication port.

B. *Software Configuration*

The simulation program presents four square path lines for the user to navigate through, using one of the switches on the TOD (see Fig. 6). When the simulation environment sends the directional message pattern using EC stimulation to the subject through the palate display, the subject depresses the corresponding switch on the TOD as a navigational guidance response. The program detects the depressed switch and moves the ball in the corresponding direction. Fig. 6 depicts the simulation environment and the ball navigation by the subject. The detailed implementation of geospatial cues is described in prior research work [4].

IV. Evaluation and Results

Psychophysical studies have previously been conducted on the palate display, to determine sensory thresholds, and to identify optimal geospatial cues [4]. In that work, it was determined that the direction of pattern motion was the primary navigational cue, whereas the specific pattern shape was not significant. However, no formal subject testing was conducted on the operation of the output device used in that study. Thus, the aim of our preliminary tests are on the TOD to assess its functionality and design.

The tests were performed on three adult human subjects over two trial sessions. To simplify the task, only four switches (one in each of the cardinal directions) were used during the operational testing of the TOD. The subjects were instructed to use the TOD to traverse a straight path across the computer screen between the two target areas (at the end of each path line) as shown in Fig. 6. The rate of movement was kept at a constant two pixels/activation of the TOD. The time it takes the subject to reach each target area can be used as an indirect indicator of the effectiveness of the TOD switches, as well as the feasibility of the two-way oral-based interface. Subject performance data and analysis is shown in Fig. 7. Data for movement in the ‘right’ direction is not available due to device failure as subjects attested that it was too difficult to activate the switch and could not complete the path. Subject feedback on comfort, functionality, and feasibility of accessing and depressing all switches was recorded and is discussed in the following section.

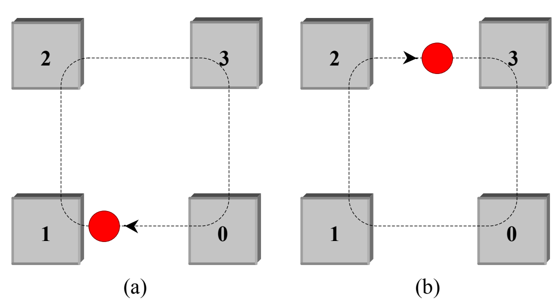

Fig. 6. TOD simulation environment. (a) Depressing the ‘left’ switch, the ball is directed from ‘Target 0’ to ‘Target 1’. (b) Depressing the ‘up’ and ‘right’ switch, the ball continues to navigate around the square path.

TOD FUNCTIONALITY

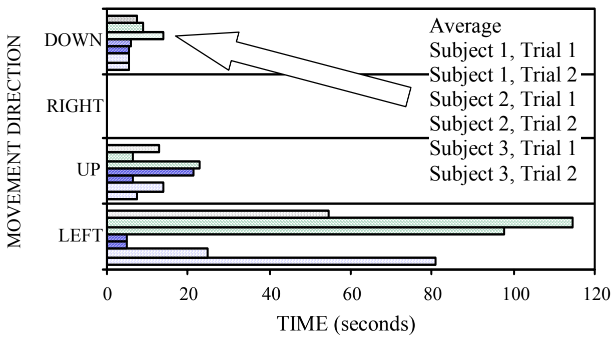

Fig. 7. The lap time taken by each subject to move the ball in each intended direction.

V. Discussion

Our preliminary tests of the operation and functionality of the TOD showed subjects were able to manipulate the device and direct the ball around the square path. Subjects could easily activate the 'up' and 'down' switches, as demonstrated by the traversal times, but reported difficulty in activating the 'left' and 'right' switches, which is exhibited in the incomplete performance times under this condition (see Fig. 7).

Subsequently, a load cell was used to determine the minimum amount of force needed to activate each switch on the TODs. The ratio of the forces is shown in Table 1. It is reasonable to assert that the discrepancy between activating the 'up/down' and 'left/right' switches is contributed to the differences in the subject performance in the tests. It is also interesting to note the range of forces the tongue can operate over, and specifically that the 'up/down' switches required more than an order of magnitude difference in force. Nonetheless, subjects were able to adapt to the different force requirements and operate the device successfully. At the same time, the 'left/right' switches, on average, required more force (as much as 20 times the minimum), and subjects had great difficulty spanning this range of force. Subsequent device fabrication must include uniform (Mylar) membrane tension, air channels to alleviate differences in air pressure at each switch, and an increase in the accuracy of the amount of epoxy deposited on top of the switches to better control the uniformity and absolute magnitude of the forces required to activate the switches.

TABLE 1
RATIO OF FORCES REQUIRED TO ACTIVATE SWITCHES ON THE TODS

	LEFT	UP	RIGHT	DOWN
1	3.0	1.4	3.0	1.0
2	3.0	1.2	3.0	3.8
3	2.0	0.3	6.0	1.4

VI. Conclusion

Preliminary tests on the implementation of a two-way active and passive oral-based tactile device have been presented. Prior work has already confirmed that the roof of the mouth is an excellent site for tactile presentation [4]. We have shown here, using the TOD, that it is also possible for the subject to send simple geospatial cues to the outside world using the tongue. The results from this and the previous study dictate that future work includes the investigation of modifying both the TOD to increase its functionality, and the palate display to improve tactile pattern perception and the quality of the EC sensation.

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